SEAW Wind Engineering Committee	**WHITE PAPER WEC #3-2023**

ASCE 7 Special Wind Regions in Washington State	**Date: February 3, 2023**
ABSTRACT: This white paper summarizes *Special Wind Region Study – Washington State and Columbia River,* a report by CPP Wind Engineering Consultants, Inc., dated 01 August 2022, and proposes revisions to the Special Wind Regions in the State of Washington. A reconfiguration of the Special Wind Region boundaries, and recommended design wind speeds for use within those boundaries is included. (Referenced chapter and section numbers, unless noted, are specifically for both the ASCE 7-16 and 7-22 editions. In this White Paper they will be referenced as ASCE 7-16/22).	**Task Group Members:** *Scott Douglas, P.E, S.E., Chair* *Don Scott, P.E, S.E.* *Russell Larsen, P.E., S.E.* *Jeff Dragovich, P.E., S.E*

COMMITTEE MISSION STATEMENT:

- *Provide guidelines for wind design and analysis issues in the Standard that are not completely clear.*
- *Provide guidance for wind design and analysis for conditions and methodology which are not in the Standard.*
- *Participate in the ICC/ASCE 7 code and standard processes to monitor/testify on wind design and analysis issues.*

The recommendations in this White Paper represent the opinion of the Task Group and the Structural Engineers Association of Washington Wind Engineering Committee (SEAW WEC). It is intended for use as a design aid reference by engineers and building officials in conjunction with their own judgement and actual project design requirements and assumptions.

I. ACKNOWLEDGMENTS:

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II. INTRODUCTION & BACKGROUND:

In 1972 the first national consensus wind speed maps and design load criteria were published as ANSI A58.1-1972. The next edition of the standard, ANSI A58.1-1982, added Special Wind Regions (SWRs). The SWRs indicated the presence of areas on the wind speed map where typical mapped design wind speeds may be, per ASCE 7-16/22 Section C26.5.2,*"substantially higher than the values indicated on the map."* It is believed these SWRs were determined by a meteorologist on the committee, without the benefit of in-depth data analysis. In 1988, ANSI 58.1 became ASCE 7-88. There have been eight subsequent editions of ASCE 7, the most recent being ASCE 7-22. Over the years, with additional data, research, and methodologies, significant wind related revisions and additions have been made to each edition. One general exception is the SWRs. The criteria and corresponding SWRs for Washington State that were originally published in ANSI A58.1-1982 are essentially unchanged in ASCE 7-16/22.

III. COMMENTARY:

ASCE 7-16/22 Section 26.5.2 for **Special Wind Regions** states: *"Mountainous terrain, gorges, and special wind regions shown in Figure 26.5-1* [the Basic Wind Speed Maps] *shall be examined for unusual wind conditions. The Authority Having Jurisdiction shall, if necessary, adjust the values given in Figure 26.5-1 to account for higher local wind speeds. Such adjustment shall be based on meteorological information and an estimate of the basic wind speed obtained in accordance with the provisions of Section 26.5.3."*

ASCE 7-16/22 Section 26.5.3 for **Estimation of Basic Wind Speeds from Regional Climatic Data** states: *"...regional climatic data shall only be used in lieu of the basic wind speeds given in Figure 26.5-1 when (1) approved extreme-value statistical analysis procedures have been used in reducing the data, and (2) the length of record, sampling error, averaging time, anemometer height, data quality, and terrain exposure of the anemometer have been taken into account."*

SWRs in Washington State are identified in ASCE 7-16/22 Figure 26.5-1 along the Pacific Coastline, along the north coast of the Olympic Peninsula, and along the western extents of the Columbia River. This is indicated by crosshatching on ASCE 7-16/22 Figure 26.5 (See Figure 1).

These SWRs are predominately in rural areas of the state where the county government is the Authority Having Jurisdiction (AHJ). These AHJs have neither the resources nor budget to determine higher local wind speeds in conformance with the requirements of ASCE 7 Section 26.5.3. Therefore, SWR wind speeds were likely determined by the individual AHJs as estimates based on local knowledge and experience. As a result, the current SWR wind speeds independently established by the State of Washington AHJs are not complete or consistent from county to county.

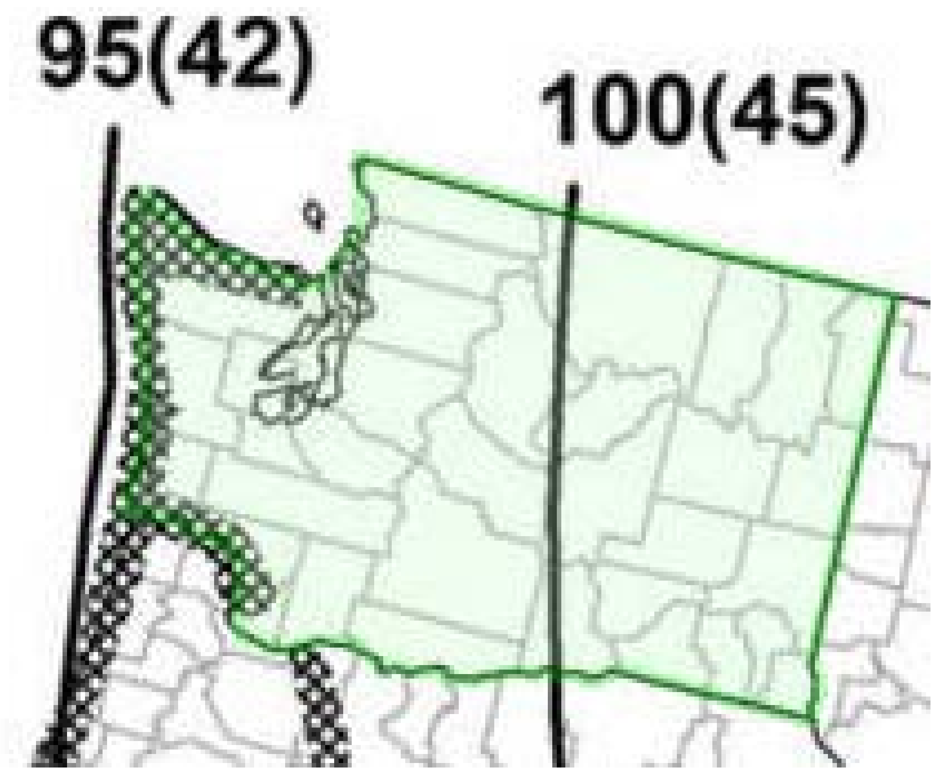

Figure 1 – per ASCE 7-16/22 Figure 26.5-1B

Recently, Colorado, Hawaii, and Kern County, California have commissioned studies that have established specific basic wind speeds and boundaries for SWRs in their jurisdictions. The SWR wind speeds determined by these studies have been included per ASCE 7-22 Sections 26.5.1, 26.5.2, and Figure 26.5-1 as part of the ASCE Wind Design Geodatabase. Based on the results of those studies, the SEAW WEC determined a similar study would be advantageous, and bring clarity to the Washington State SWRs. This would be the first review since the 1982 creation of the SWRs in Washington State.

The SEAW WEC commissioned CPP Wind Engineering Consultants, Inc. of Windsor, Colorado to perform a study of regional climatic data influencing the Washington State SWRs. The analysis would result in recommendations for wind speeds in the SWRs for Washington State in conformance with the provisions of ASCE 7-16/22. CPP is a nationally recognized wind engineering consultant, has performed similar work for SWRs in Colorado and California, and has been involved in the peer review of the ASCE 7-16/22 wind maps. CPP's final study and report recommendations are included in Appendix A.

IV. RECOMMENDATIONS:

The SEAW Wind Engineering Committee endorses the recommendations in CPP's August 1 report, and advocates for their adoption by the AHJs within the Washington State SWRs. The Wind Engineering Committee also recommends that the Washington State Building Code Council review and adopt CPP's recommendations at the State level, and that the revisions be submitted for approval and inclusion in ASCE 7-28. It is anticipated that inclusion in ASCE 7-28 will be per the Wind Design Geodatabase and Figure 26.5-1 Footnote 6.

Specific recommendations for Washington State developed by CPP and endorsed by the SEAW WEC are:

- An SWR is not warranted along the east portion of the north coast of the Olympic Peninsula, including Jefferson County and the portion of Clallam County east of longitude -124.00. Wind speeds should follow the Risk Category design speeds per the ASCE 7-16/22 ASCE Figure 26.5-1 wind maps.
- An SWR is not warranted along most of the Columbia River, including the counties of Walla Walla, Benton, Klickitat, Skamania, Clark, Cowlitz, and the portion of Wahkiakum County east of longitude -123.33. Wind speeds should follow the Risk Category design speeds per the ASCE 7-16/22 ASCE Figure 26.5-1 wind maps.
- The SWR along the Pacific Coast should be reconfigured as identified in Figure 2 to include the portion of Clallam County west of latitude -124.00, the portions of Jefferson County, Grays Harbor County, and Pacific County within 15 miles of the Pacific coastline, and the portion of Wahkiakum County west of longitude -123.33. Recommended design wind speeds in the revised SWR are presented in Table 1 below.

Risk Category (MRI)	Basic Ultimate Wind Speed (mph)
I (100 years)	115
II (700 years)	120
III (1700 years)	130
IV (3000 years)	140

Table 1 –Recommended SWR Wind Speeds Along Washington's Pacific Coast

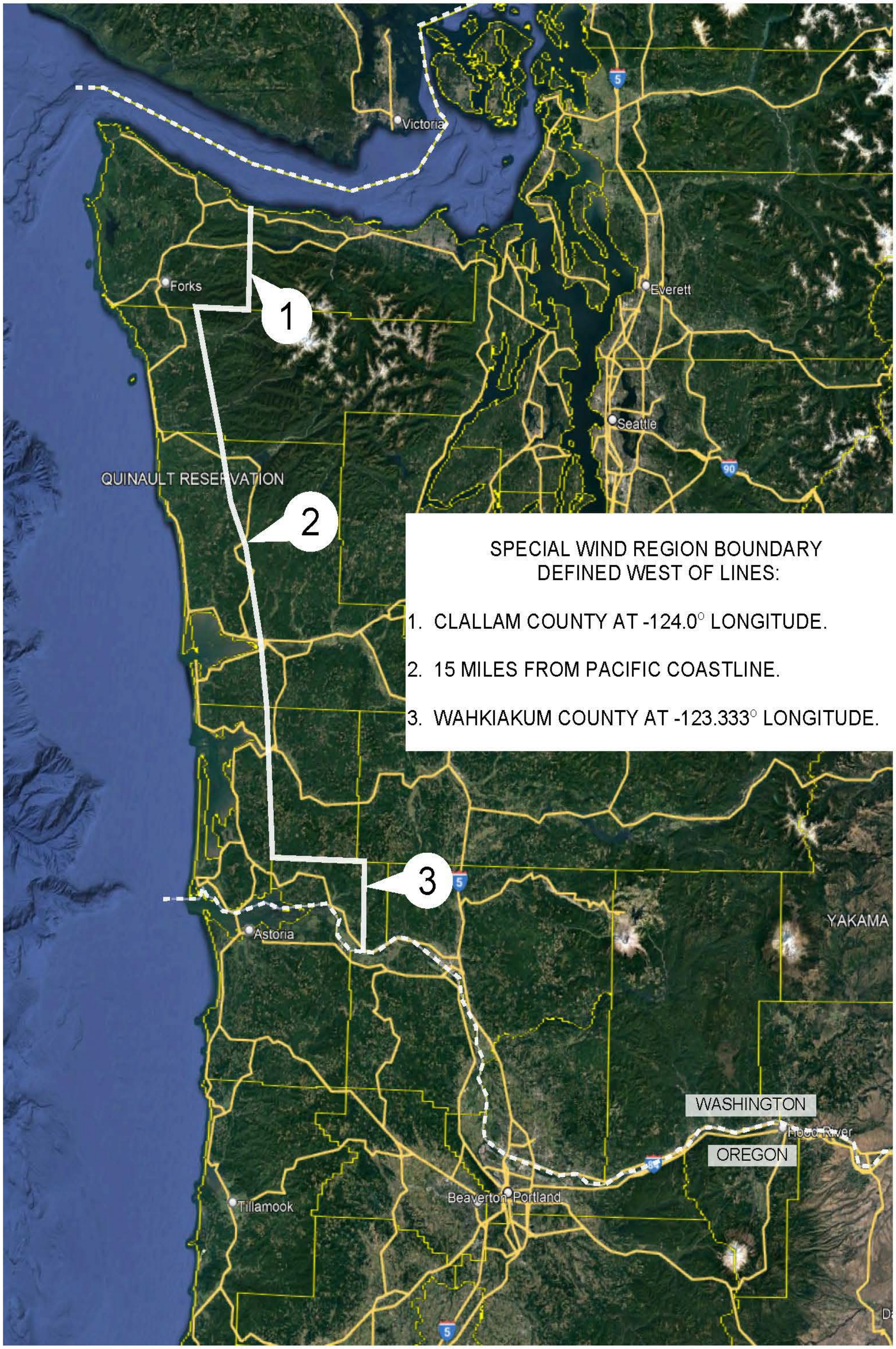

Figure 2 – Recommended Washington State SWR Boundary

APPENDIX A

SPECIAL WIND REGION STUDY

WASHINGTON STATE AND COLUMBIA RIVER

BY CPP, INC.

01 AUGUST 2022

FINAL REPORT

CPP PROJECT 16166
1 AUGUST 2022

SPECIAL WIND REGION STUDY

Washington State and Columbia River

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EXECUTIVE SUMMARY

The goal of this study was to examine the available wind data along the Columbia River, Washington Coast, and Olympic Peninsula to determine if a modification to the ASCE 7-16 and its successor ASCE 7-22 (*from this point forward, these 2 standards will collectively be referred to as "ASCE 7-16/22"*) special wind region (SWR) boundary is justified.

CPP has previously contributed to the determination of design wind speeds for SWRs in Colorado[1] and California[2,3], and David Banks led the effort to incorporate these modified SWRs into the recently published ASCE 7-22. In every instance, close examination of the wind data from these regions altered the SWR boundaries, eliminating portions of SWRs or expanding the boundaries elsewhere.

To the best of our knowledge, the wind map SWRs were added to the 1982 ANSI standard by a meteorologist who was a member of the committee at that time. Since then, no review of the SWRs along the Columbia River, Pacific Coast, or Olympic Peninsula has been conducted to our knowledge. We evaluated wind data from stations both inside the SWR and surrounding areas for comparison. In some cases, the SWRs extend into areas where there is no distinguishable difference in wind climate between the SWR and neighboring areas, and this is not surprising provided that the regions were created in 1982 with unknown basis.

This study confirms the need for the SWR along the Pacific Coast. Figure 1 shows the recommended SWR boundary. Strong low-pressure systems just offshore in the Pacific often bring high southerly winds along the coast. The resulting 10+ year Mean Recurrence Interval (MRI) speeds are greater than those provided for this region in ASCE 7-16/22 absent the SWR. We expect these high winds are often restricted to the immediate coastal area and rapidly decrease moving inland.

Our analysis found that a uniform design wind speed for the Washington Coast is a suitable reflection of winds brought by these low-pressure systems, and subsequently we recommend the following basic wind speeds for the entirety of the Washington Coast:

Risk Category (MRI)	Basic Wind Speed, $\hat{U}$ (mph)
I (300 years)	115
II (700 years)	120
III (1700 years)	130
IV (3000 years)	135

[1] Colorado Front Range Gust map, https://seacolorado.org/docs/FINAL-COLORADO-FRONT-RANGE-GUST-MAP-2013.pdf

[2] 2016 Kern County Code of Building Regulations, https://kernpublicworks.com/wp-content/uploads/2020/01/2019-Kern-County-Code-of-Building-Regulations-FINAL.pdf

[3] Recommendations For Action To Address Design Wind Speed In California, https://seaoc.site-ym.com/store/ViewProduct.aspx?id=9639114&hhSearchTerms=%2522special+and+wind+and+region%2522

These wind speeds apply within a uniform distance from the coast to approximately 15 miles inland, which roughly matches the current SWR boundary. Our approximate 15-mile inland boundary is from the Pacific Coast, even in regions with inland bays as indicated in Figure 1.

Our study also found that the boundaries of the ASCE 7-16/22 Columbia River SWR encompassed many locations that do not have unusually high wind speeds compared to the ASCE 7-16/22 design speeds. As such, CPP recommends that the special wind region along the Columbia River be amended to follow the Risk Category design speeds from the ASCE 7-16/22 wind maps for all counties east of and including Cowlitz County in Washington. Due to the lack of weather stations in Wahkiakum County that would help define the transition and reductions from the strong coastal winds moving inland, we recommend the Washington Coast design wind speeds also be used in Wahkiakum County.

In Oregon, the Columbia County SWR designation can be removed and replaced to follow the Risk Category design speeds and MRIs from the ASCE 7-16/22 wind maps. The Clatsop County current SWR boundary should remain with design wind speeds of 120 and 130 mph for Risk Category II and III, respectively. The Clatsop County design speeds by Risk Category follow the Washington Coast recommendations.

Based on our experience with local AHJs and wind speed boundaries, it is typically more beneficial for the local authority when the wind speeds are defined at the county boundary as was done for the Columbia River SWR, even if the longitudinal position does not align across the river. If a longitudinal boundary is preferred, then we recommend -123.333°.

Similar to the Columbia River SWR, our study found that the Olympic Peninsula's eastern, north coast does not warrant a special wind speed designation. Only the western portion of Clallam County should remain as an SWR, and this region should follow the Washington Coast design speed recommendations by Risk Category. These regions should include Clallam Bay, Pillar Point, Beaver, and Forks; the SWR boundary transition in Clallam County is about 35 miles inland from the Pacific Coast at a longitude of -124.00°. The eastern regions of the county (Port Angeles, Lake Dawn/Foothills, Diamond Point, and Sequim) should follow the Risk Category design speeds from the ASCE 7-16/22 wind maps.

The CPP design wind speed recommendations are based on a three-second gust speed at 33 ft above the ground in Exposure C (open country) to follow the design basis of ASCE 7. Any locations where Exposure Category D (ocean and water surfaces) would be required, the velocity pressure coefficient (K_z) would effectively increase the wind speed and loads through the application of K_z by height.

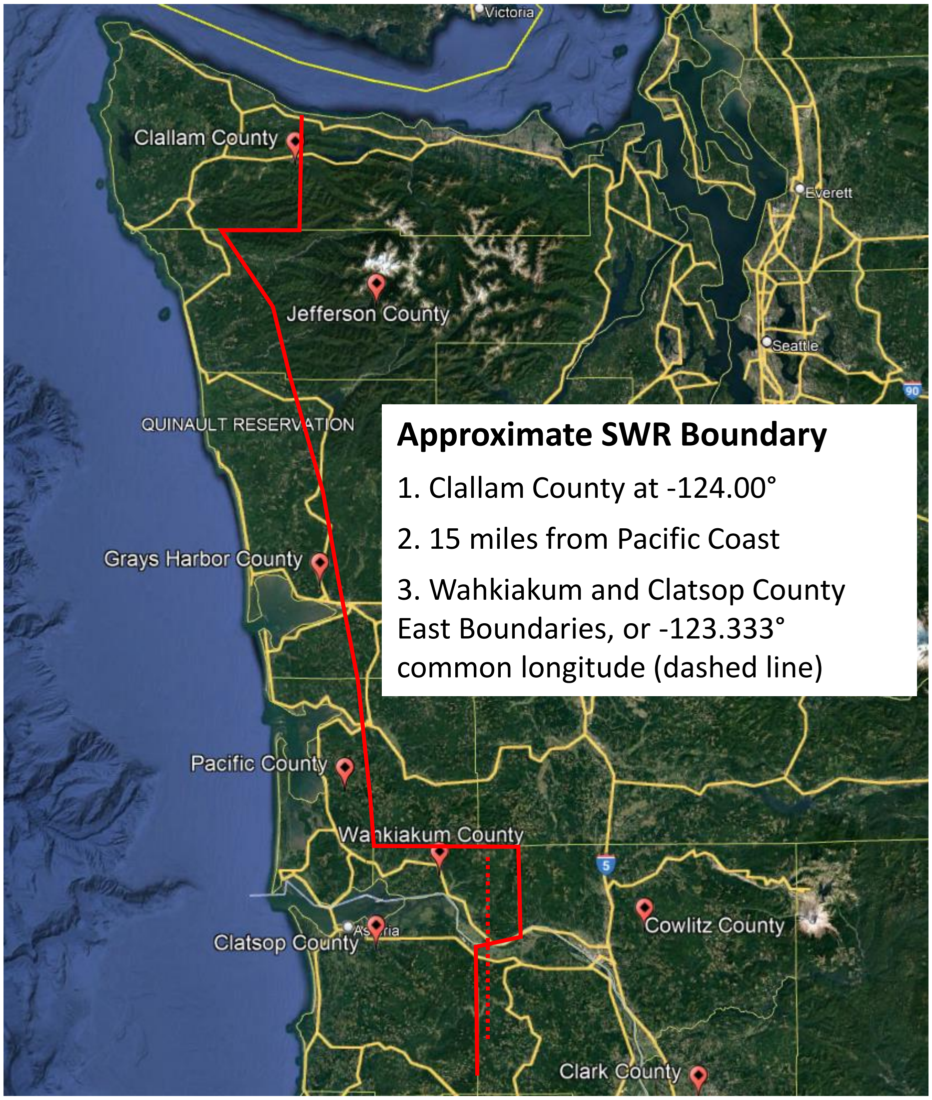

Figure 1. *Washington State and Columbia River SWR boundary*.

BACKGROUND

The American Society of Civil Engineers Standard, Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7-16/22) provides wind speed maps for use in the calculation of design wind loads for structures. These maps have, beginning with the 1982 ANSI standard, indicated the presence of special wind regions (SWRs) for which the typical mapped design speeds do not apply. ASCE 7 states that the SWRs account for "*known wind speed anomalies*" where speeds "*are substantially higher than the values indicated on the map*". In other words, for these local areas, the regional wind speed patterns captured in the ASCE 7 wind maps are in theory not adequate. Possible reasons cited for these SWRs include "*winds blowing over mountain ranges or through gorges or river valleys*", which could explain why the Columbia River and Olympic Peninsula were initially considered.

ASCE 7 does not indicate how to account for these wind speed anomalies, stating only that "*the authority having jurisdiction shall, if necessary, adjust the values given in Fig. 26.5-1 to account for higher local wind speeds. Such adjustment shall be based on meteorological information and an estimate of the basic wind speed obtained in accordance with the provisions of Section 26.5.3*." Additional guidance from 7-16/22 includes, "*The basic wind speed shall be increased where records or experience indicate that the wind speeds are higher than those reflected in Figure 26.5-1.*"

WASHINGTON COAST

The ASCE 7 commentary mentions that the SWR along the Pacific Coast is due to limited data. "*Limited data were available on the Washington and Oregon coast. In this region, a special wind region was defined to permit local jurisdictions to select speeds based on local knowledge and analysis.*" Figure 2 shows the approximate boundary of the SWR along the Washington Coast. No specific wind speeds are prescribed in this region by ASCE 7-16/22, which leads to the local AHJs implementing their own requirements.

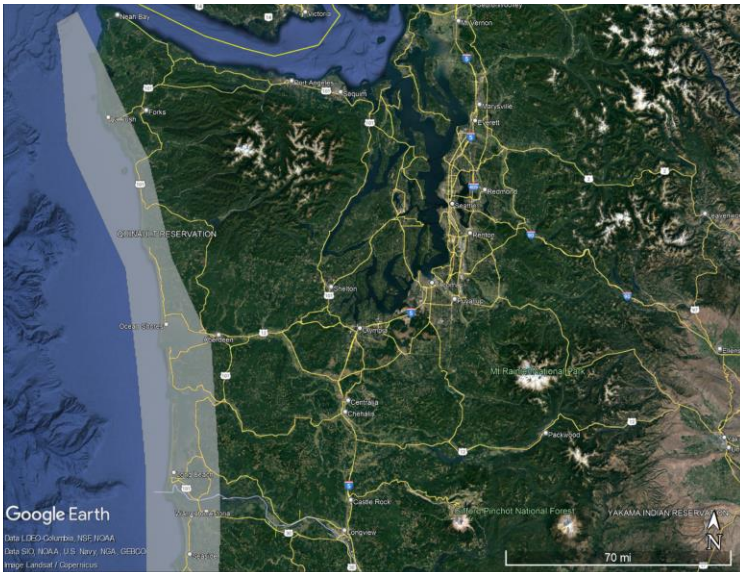

Figure 2. *Washington Coast SWR approximate boundary as indicated in ASCE 7-16/22.*

The Washington State coastal counties have implemented design wind speeds that range from 115 to 130 mph based on a Risk Category II classification (700-year MRI). The Grays Harbor County design wind speed of 115 mph (Risk Category II basis) along the coast is the single outlier in this SWR. The other three counties require 130 mph for a Risk Category II basis along the Pacific Coast, with Clallam County reducing this design speed to 120 mph at the Forks and Beaver locations.

COLUMBIA RIVER

Figure 3 shows the approximate boundary of the SWR along the Columbia River. Again, no specific wind speeds are prescribed in this region by ASCE 7-16/22, which leads to most local AHJs implementing their own requirements.

Figure 3. *Columbia River SWR approximate boundary as indicated in ASCE 7-16/22*.

The Washington counties of Pacific, Clark, and Skamania along the Columbia River have implemented design wind speeds above ASCE 7-10 and 7-16 (Figure 4). The design speeds in these counties range from 130 to 155 mph based on Risk Category classification. Cowlitz and Klickitat counties prescribe design speeds equal to 7-10 values. Wahkiakum is an outlier at 85 mph, which is likely based on the older ASCE 7-05 standard centered around a 50-year MRI, although the county does reference the 2015 International Building Code that uses ASCE 7-10 as the design basis for wind loads. The design wind speed of 85 mph does not match the 7-10 strength design level wind speeds and would require a load factor to convert to ultimate strength.

The Oregon counties of Clatsop and Columbia along the Columbia River have also implemented design wind speeds above ASCE 7-10 and 7-16 (Figure 4). The 2019 Oregon Structural Specialty Code (OSSC) lists the design speeds in these counties from 115 to 145 mph based on Risk Category I, II, III and IV classifications.

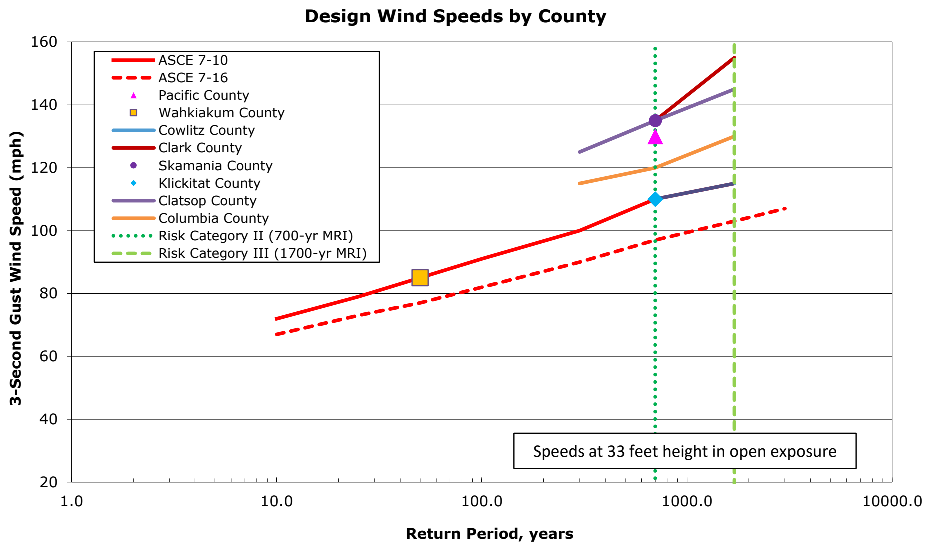

Figure 4. *Local AHJ design wind speeds by county in the Columbia River SWR.*

OLYMPIC PENINSULA

Figure 5 shows the approximate boundary of the SWR along the Olympic Peninsula. The Clallam County design wind speeds range from 110 to 130 mph based on a Risk Category II classification (700-year MRI). Again, the Pacific Coast speed of 130 mph is reduced to 120 mph at the Forks and Beaver locations. This design wind speed is further reduced to 110 mph at the eastern regions of the county (Port Angeles, Lake Dawn/Foothills, Diamond Point, and Sequim).

Figure 5. *Olympic Peninsula SWR approximate boundary as indicated in ASCE 7-16/22.*

METHODS

As recommended in ASCE 7-16/22, special wind regions as specified in the wind maps should be examined for unusual wind conditions per Section 26.5.2. When determining a site-specific wind speed, Section 26.5.1 of ASCE 7-16/22 refers us to Section 26.5.3, called "Estimation of Basic Wind Speeds from Regional Climatic Data." It states,

> *In areas outside hurricane-prone regions, regional climatic data shall only be used in lieu of the basic wind speeds given in Figure 26.5-1 when (1) approved extreme-value statistical-analysis procedures have been used in reducing the data; and (2) the length of record, sampling error, averaging time, anemometer height, data quality, and terrain exposure of the anemometer have been taken into account. Reduction in basic wind speed below that of Figure 26.5-1 shall be permitted.*

Recommendations for reductions in basic wind speed below those in ASCE 7 are beyond the scope of this study. This study aims to identify regions of the Washington State SWRs with wind speeds above those in ASCE 7-10 and ASCE 7-16/22, and to quantify those speeds where possible.

During our study, we fulfilled both conditions (1) and (2). We have used approved procedures described by Palutikof et al. (1999), including the same extreme value statistical procedures that were used to develop the ASCE 7-16/22 wind speed map. Key staff at CPP were involved in the peer review of these wind maps, so we are familiar with their derivation. The recommendations in this study are based on the same kind of extreme value statistical analyses that provided the basis for the ASCE 7 wind maps over the past two decades (Peterka and Shahid 1998), with improved procedures for storm type separation and the use of multiple storms per year.

DATA SOURCES

The primary data used in this analysis originate from Automated Surface Observing System (ASOS) and Automated Weather Observation Systems (AWOS) anemometers. ASOS and AWOS stations were established by the United States government "to provide the nation a highly cost-effective, capable and reliable automated weather observing system for safe, efficient aviation operations and other applications" (U.S. Dept. of Commerce et al. 1998). These observing systems were implemented at over 900 U.S. airports throughout the mid-1990s through early 2000s.

Data quality generally significantly improves after ASOS and AWOS implementation because of the quality-assurance measures put in place. Mean wind data consist of two-minute averages. Gusts are generally 5-second averages, with most ASOS stations switching from cup to sonic anemometers (with 3-second averaging intervals) in the mid- to late-2000s. Reported gusts are the highest 5- (or 3-) second averages occurring in the previous 10 minutes. The datasets used in this analysis consist of mean and gust wind data recorded on average once-per-hour, with reports increasing to every 15 minutes or less when high wind speeds are present. This decreases issues with sampling error, ensuring that peak wind speeds are properly recorded when they occur.

ASOS and AWOS anemometers are most commonly standardized to a height of 33 ft, while some are located at 26 ft. A height adjustment was applied to the data as necessary for any anemometer not already located at 33 ft. The 5-sec-averaged gust speeds at each airport were increased to match the 3-sec-averaged gust speeds as necessary.

We reviewed the available wind data from the National Centers for Environmental Information (NCEI) for the ground-based weather stations located near and inside the SWRs to gain an understanding of the wind climate in this area. Several stations identified in the region were excluded because of low data completeness, or the length of period of record was too short to produce a reliable result. After analysis some stations were deemed unrepresentative, and their results were excluded. A complete list of stations considered, and which ones were included is provided in Appendix A. The TD3505 (hourly data) were used in this analysis along with the peak wind from the METAR observation reports. The NCEI recommends that the GHCN[4] peak daily data be used to predict peak gust speeds, rather than the TD3505 (Seiderman, 2015). These records generally do not match perfectly and using the METAR observation report negates any concern. The ASCE 7-16/22 wind maps are based on TD3505 data. This is because it is easier to isolate peak gusts due to thunderstorms in the hourly data, which is necessary for storm-type separation (see below).

In addition to the hourly data from NCEI, one-minute gusts were also analyzed. The one-minute data were compared to the hourly data but were found to often have missing data during some storm events. As with the hourly data, the one-minute ASOS data were subjected to the same quality control and statistical analysis procedures. The recommended wind speeds in this report consider all the available data. By implementing the use of multiple data sets, we are confident in the quality of the data and extreme wind speeds used in our analysis that ultimately guide our recommendations.

As part of our quality assurance, thorough quality control (QC) procedures were performed on all data to determine what extreme speeds are reliable for an extreme value analysis. As typical, there were several outliers where the wind data were not considered reliable and thereby not utilized. The first step of our process is to remove erroneous data points, of which an example is provided in Figure 6. Gust speeds (red circles) of 20 mph were reported around 4am, followed by a significant increase to 100 mph by a single measurement point without a corresponding increase in mean wind speed (blue dots). This extremely high gust speed is erroneous, which is also confirmed by the one-minute gusts (small light red squares) that did not exceed 25 mph around the time of the erroneous gust observation.

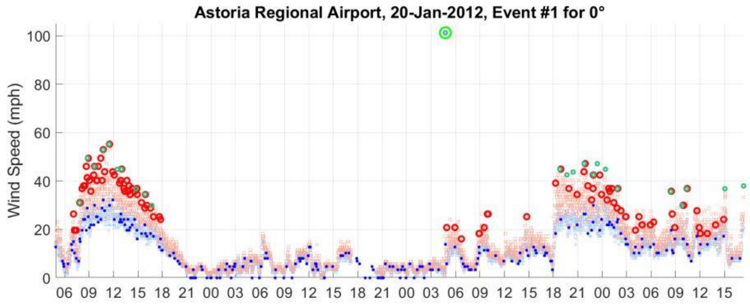

Figure 6. *Time series of wind speeds for quality control.*

[4] GHCN data is described here: http://www1.ncdc.noaa.gov/pub/data/cdo/documentation/GHCND_documentation.pdf

No wind speed data other than from NCEI airport anemometers was used, as it was outside of the scope of this study to analyze such anemometers and perform quality checks on the data. It is possible that there are specific locations where the river gorge creates significant channeling for some wind directions. This kind of channeling, however, was not obvious in the observations we analyzed. Identifying areas of channeling would be better served by site specific topography simulations (as would the base for exposed mountain tops or ridges, see below) rather than a blanket of uncertain wind speeds extended several miles on either side of the river.

SEPARATING BY STORM TYPE

It is well known that different storm types will produce different extreme wind probability distributions. This is one reason why hurricane winds have traditionally been analyzed separately from other wind events. The analyses for the wind maps in ASCE 7-16/22 also isolate thunderstorms, and Figure 7, taken from the ASCE 7-16 wind map "Rationale for Changes" document, indicates that thunderstorms are not expected to be significant in the Pacific Northwest.

Storm separation has been performed for this study, and indeed thunderstorms winds were much less severe than other types of wind events at all stations examined. Thunderstorms were identified by reviewing the directionality of each storm as well as the duration; thunderstorms produce a rapid increase in wind speeds and can last from a couple of minutes to several hours. As estimated by ASCE 7 and shown in Figure 7, our analysis confirms that the occurrence of thunderstorms is low and does not significantly contribute to the controlling design wind speeds in or near these SWRs.

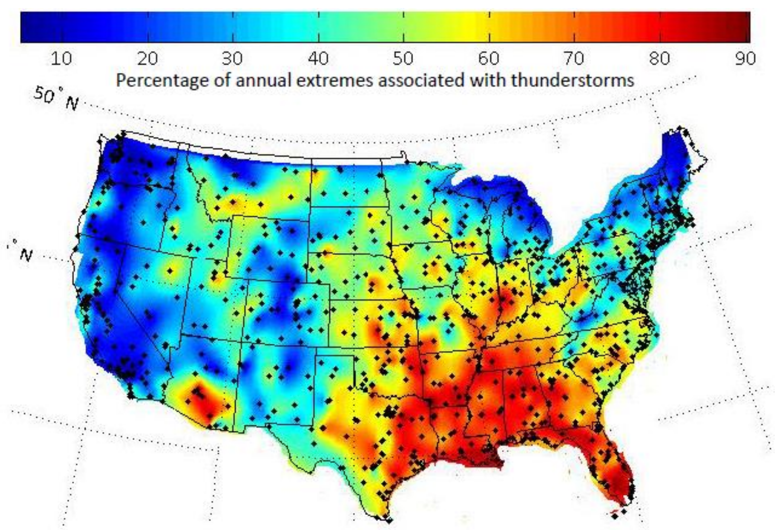

Figure 7. *Percentage of annual extreme wind speeds associated with thunderstorms, a rationale for 7-16 wind map*.

EXTREME VALUE CURVE FITS

The extreme value analysis methods used in this study are well described in Palutikof et al (1999). We have assumed a Fisher–Tippett Type 1 generalized extreme value distribution, also known as the Gumbel distribution. This is potentially conservative for MRIs longer than 300 years, as the severity of winds for any given storm type is not unlimited.

In this study, we fit peak wind gust data to this distribution using a Weighted Least Squares (WLS) method. This is a graphical method with an alternative fitting strategy to account for the error associated with each point being greatest for the largest extremes. As there were generally too many points for the Lieblein BLUE method, we employed a Monte Carlo simulation to determine the expected errors for each point. The normalized errors were then minimized using least squares. The reduced variate (based on the recurrence intervals) was unbiased using Gringorten's formula, as described by Palutikof et al (1999). There are other methods of fitting the data, including a linear least squares fit, the Maximum Likelihood Estimates (MLE), and the Method of Moments (MoM). The predictions from these three methods typically varied by under 5%.

The WLS fitting technique described above was applied to both annual peak gusts, and to peak wind gusts from independent storms. The results of this Method of Independent Storms (MIS) also vary with the number of storms selected. We have followed the recommendations of Cook (2014) and limited the fitting range to roughly 3 storms per year. The selection of data used in the fitting introduces an uncertainly of around 5%.

The largest source of uncertainty, however, is typically the duration of the weather record. A graph of extreme wind speeds from the Astoria Regional Airport and their associated return periods is shown in Figure 8. The Monte Carlo simulation used in the WLS method is also used to interpret the significance of variability in the data (i.e. to examine the goodness-of-fit). If the fit is accurate, then 95% of time the wind speeds should fall between the red lines in Figure 8. There is only a 5% chance that a data point will lie either above or below these lines – 2.5% on each side, so points outside these lines generally indicate a poor fit.

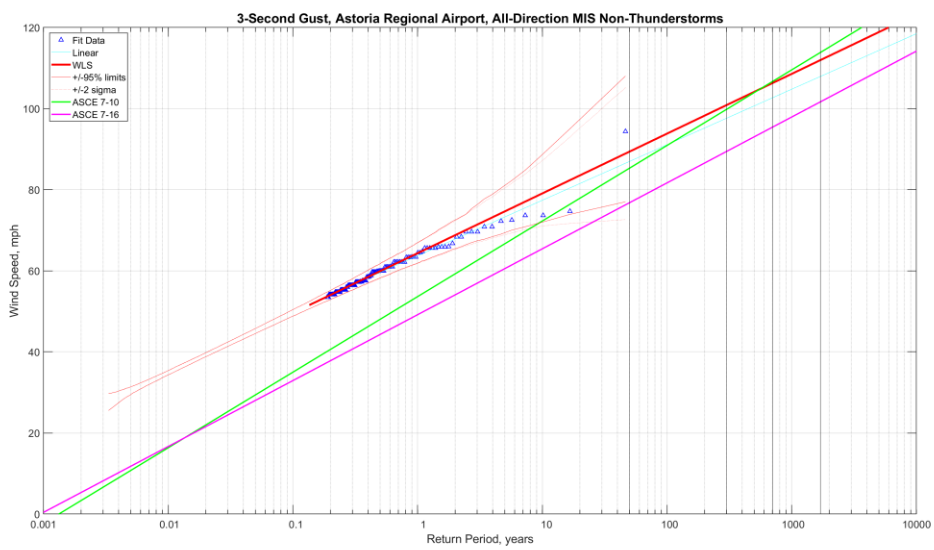

Figure 8. *Gumbel fit to non-thunderstorm wind events at Astoria Regional Airport*.

LONG TERM MRI EXTRAPOLATION

To improve the accuracy of the 700-year MRI wind speed predictions, multiple nearby weather stations can be combined to form a “superstation” (Peterka and Shahid 1998). However, stations that have significantly different wind conditions cannot be combined in this manner. Because the River Valley winds change rapidly with distance from the mountains and valleys, creation of superstations was not possible for this analysis. However, there were generally enough data to reliably predict the 50-year wind speed.

Extrapolation from 50-year to MRI’s longer than 300-years has inherent uncertainty but is more accurate than applying a uniform load factor to all wind climates. It is generally considered conservative to use a linear Type I fit to the data (as we have done here), as wind speeds are not expected to indefinitely increase linearly with the log of the MRI; eventually, some meteorological or physical limit is approached. For this reason, some researchers have suggested a Type III fit, with a wind speed plateau, is more appropriate (for example, see Holmes and Moriarty 1999).

WIND CLIMATE ANALYSIS RESULTS AND RECOMMENDED SWR CHANGES

WASHINGTON COAST

Historic peak gust records from the airports along the Washington Coast SWR (Figure 9) were used in the analysis of local peak gust design wind speeds. It was found that this region often experiences powerful midlatitude or extratropical cyclones (ETCs). These low-pressure weather systems regularly produce intense storms over the Pacific Ocean that routinely impact the Pacific Northwest coast. While the cool waters of the Pacific prevent tropical cyclones from reaching the shores of the Pacific Northwest, ETCs often develop in this region. The analysis from this study confirms that these synoptic storms determine the design wind speeds along the Washington Coast. Figure 10 shows the variation of wind speed with MRI using a Gumbel (Type I) distribution. The return period is plotted on a logarithmic scale to permit examination of wind speed over a wide range of MRIs.

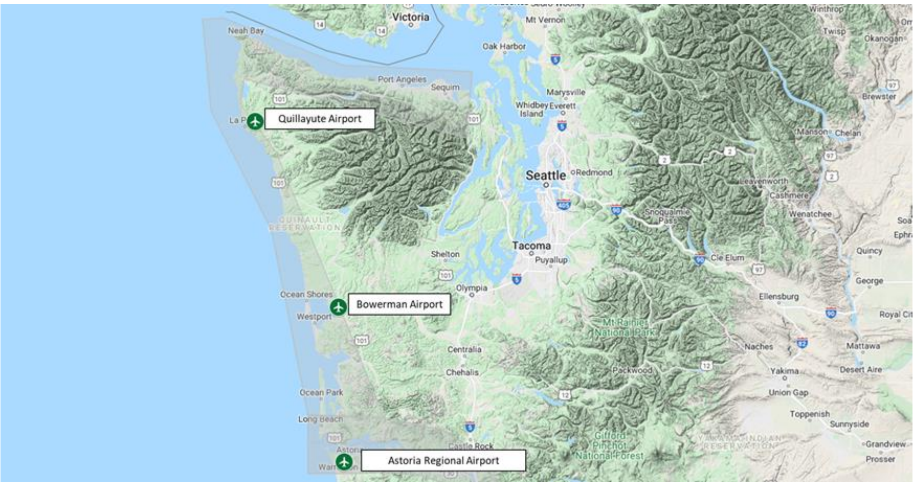

Figure 9. *Location of weather stations along the Washington Coast*.

After accounting for exposure, the analysis from each of the airports along the Washington Coast confirms that the coast does indeed warrant a SWR as the all-direction $\hat{U}_{700}$ (Risk Category II) and $\hat{U}_{1700}$ (Risk Category III) design wind speeds are above the ASCE 7-16 values of the immediate area. Considering this, and that the ETCs are expansive and can impact the entire coast, we recommend a uniform $\hat{U}_{700}$ of 120 mph along the coast to encompass these impacts. The design wind speed recommendations by Risk Category are provided in the Executive Summary.

The synoptic-scale events that cause these high winds along the coast have rapidly decreasing impacts moving inland, reserving the strongest winds to the immediate coastline. While we recommend the SWR along the Washington Coast remain, we have recommended modifications to the extension of this coastal SWR into the Columbia River and Olympic Peninsula in consideration of this rapid decrease in winds moving inland.

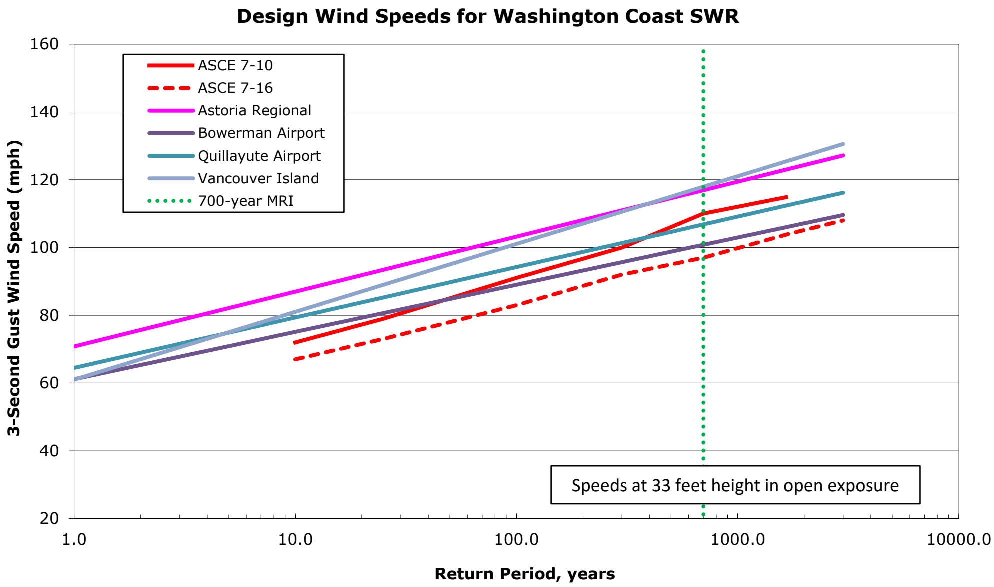

Figure 10. *Gumbel fits to non-thunderstorm wind events for all airport meteorological stations along Washington Coast.*

COLUMBIA RIVER VALLEY

Historic peak gust records from the airports along the Columbia River SWR (Figure 11) were used in the analysis of local peak gust design wind speeds. Synoptic storms, including ETCs, determine the design wind speeds in the Columbia River Valley. Figure 12 shows the variation of wind speed with MRI using a Gumbel (Type I) distribution. Again, the return period is plotted on a logarithmic scale to permit examination of wind speed over a wide range of MRIs.

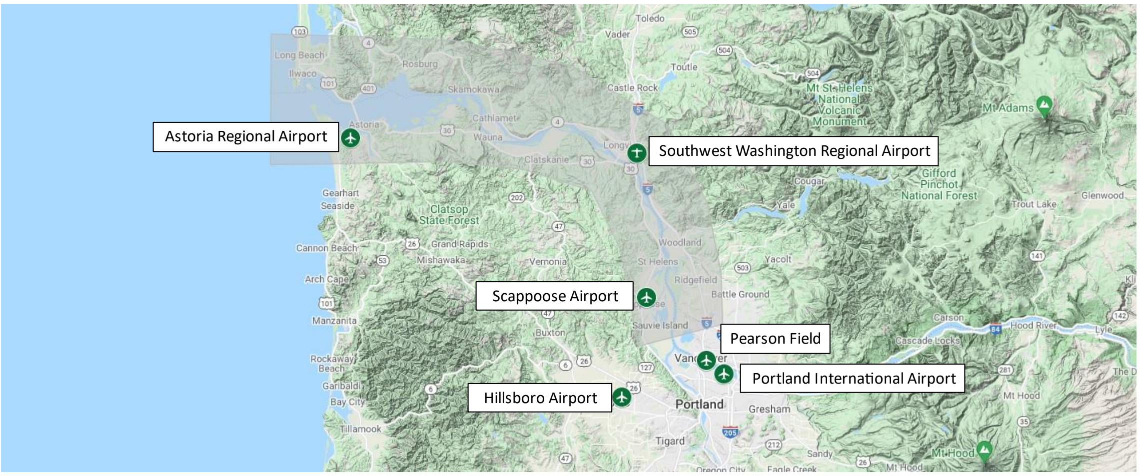

Figure 11. *Location of weather stations along the Columbia River*.

The all-direction $\hat{U}_{700}$ (Risk Category II) and $\hat{U}_{1700}$ (Risk Category III) design wind speeds are below the ASCE 7-16 values at all the locations except for Astoria Regional Airport (Figure 12). Wind speeds at Portland International, which was included in the ASCE 7-10 SWR, are a good match to the ASCE 7-16 wind map values. The Portland area was excluded from the SWR in ASCE 7-16. The other stations show design speeds below the Portland International analysis, indicating that the SWR designation can be removed for most of the counties along the Columbia River.

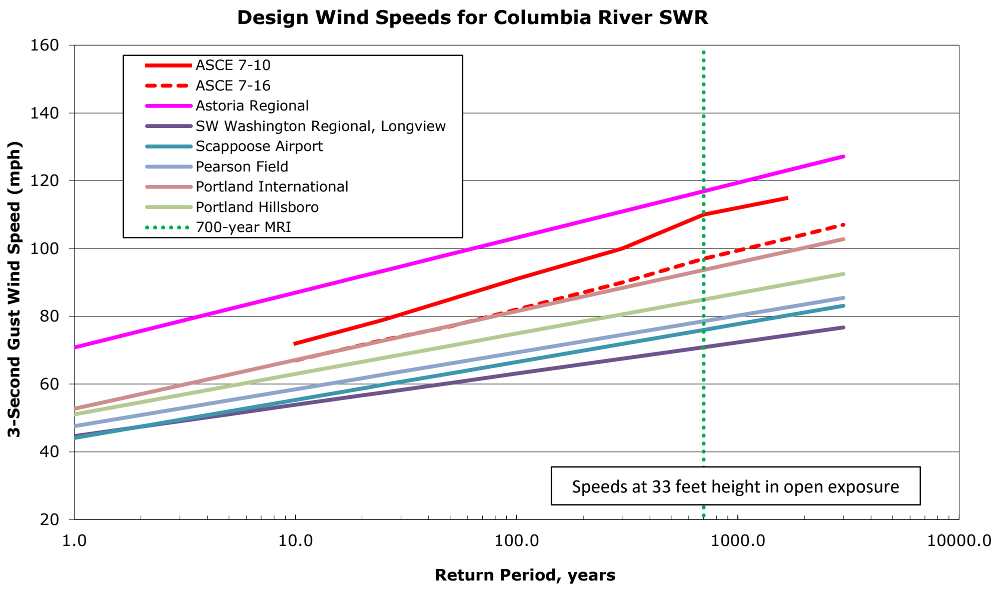

Figure 12. *Gumbel fits to non-thunderstorm wind events for all airport meteorological stations along Columbia River*.

Astoria Regional Airport, located at the mouth of the Columbia River on the Washington Coast, revealed design wind speeds higher than ASCE 7-16 and confirms that the Washington Coast does warrant a SWR. Considering these higher wind speeds measured at Astoria, we researched the weather history of the Pacific Northwest to determine if any unique conditions or weather patterns could create a special wind region designation along the Washington coastline that would extend into the Columbia River. To verify the extent of these extreme events, CPP compared the largest storm events measured at the Astoria Regional Airport to the other anemometers in the Columbia River SWR. The Great Coastal Gale of 2007 impacted Astoria on December 3, 2007, with peak gust wind speeds up to 95 mph. For comparison, the other stations in the Columbia River SWR measured much lower gust speeds (ranging from 40 to 50 mph) during this storm event (Figure 13). This provides evidence that these strong weather events do not produce similar wind speeds farther inland. Other large wind events show similar trends, such as the Hanukkah Eve windstorm of 2006.

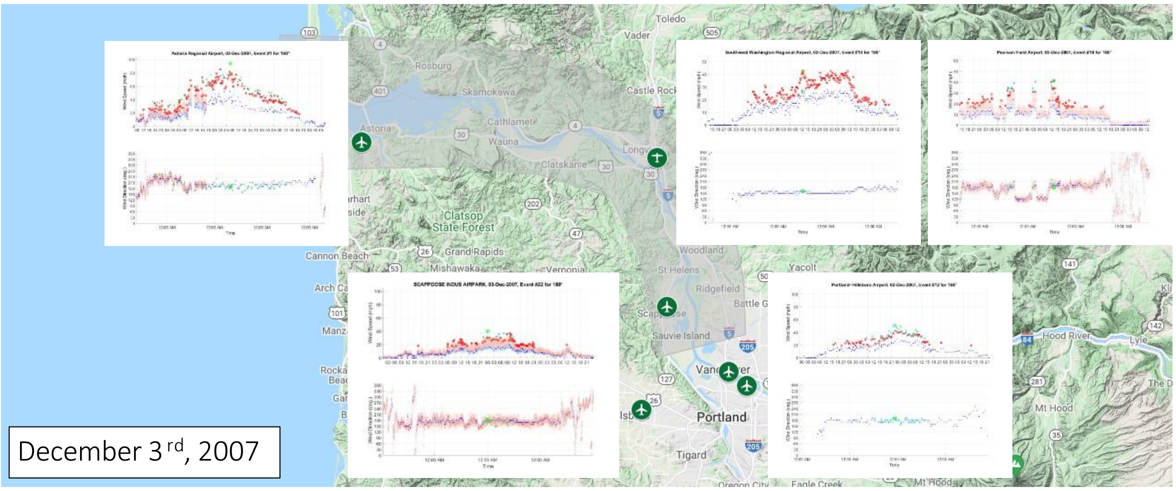

Figure 13. *Regional wind speeds during the 2007 Great Coastal Gale.*

The Ides of October storm of 2016, which became extratropical from the remains of Typhoon Songda, serves as another example of how speeds rapidly decrease as you move away from the coast. A map depicting surface winds from the NCEP Reanalysis dataset in Figure 14 show that the system generated the largest wind speeds along the coast with vastly reduced speeds moving inland along the Columbia River. While this imagery is beneficial to our analysis and confirms the overall wind climate patterns, the anemometer observations were used to determine the recommended all-direction wind speeds.

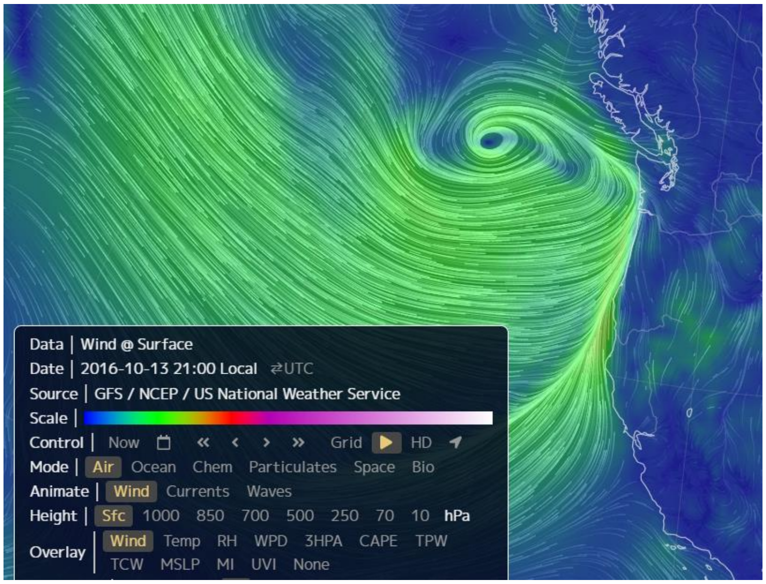

Figure 14. *Surface winds from the NCEP Reanalysis dataset during the October 2016 storm.*

We recommend that the special wind region along the Columbia River be amended to follow the Risk Category design speeds from the ASCE 7-16 wind maps for all counties east of and including Cowlitz County in Washington. Due to the lack of weather stations in Wahkiakum County that would help define the transition from the strong coastal winds, we recommend that the Pacific County design wind speeds also be used in Wahkiakum County.

In Oregon, the Columbia County SWR designation can be removed and also replaced to follow the Risk Category design speeds from the ASCE 7-16 wind maps.

If a longitudinal boundary is preferred over the offset, eastern boundaries of Wahkiakum and Clatsop Counties, then we recommend a longitude value of -123.333°.

Historic peak gust records from additional weather stations along the Columbia River between Portland and Dallesport (Troutdale, Hood River, and Columbia Gorge Regional Airport) were also included in the design wind speed analysis, see Appendix A. As indicated in ASCE 7-16/22, this region does not appear to warrant a SWR from the limited wind speeds measured at these ASOS and AWOS stations. Troutdale speeds are similar to Portland International, Hood River lacks historic wind data, and the Dallesport all-direction design wind speeds are below the ASCE 7-16/22 values across all Risk Categories.

OLYMPIC PENINSULA

Figure 15 shows the location of historic peak gust records from the airports along the Olympic Peninsula SWR that were used in the analysis. As with the Columbia River and Washington Coast SWRs, synoptic scale systems, including ETCs, determine the design wind speeds for the Olympic Peninsula region.

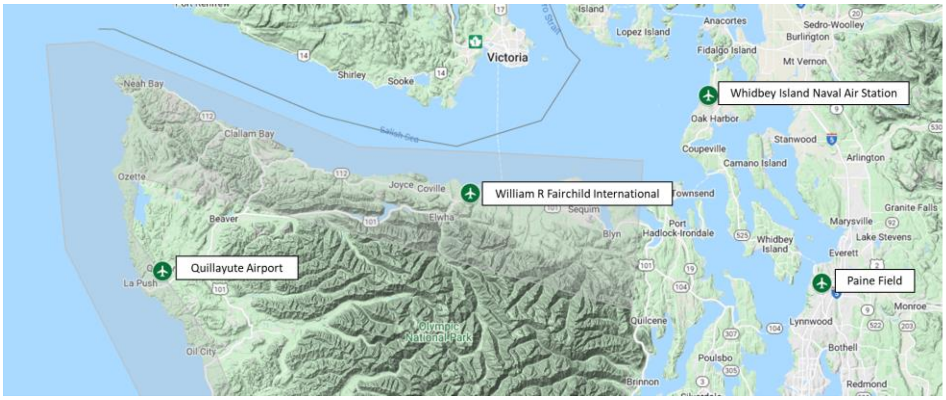

Figure 15. *Location of weather stations along the Olympic Peninsula.*

Figure 16 shows that the all-direction $\hat{U}_{700}$ (Risk Category II) and $\hat{U}_{1700}$ (Risk Category III) design wind speeds are below the ASCE 7-16 values at all locations, except Quillayute along the Pacific Coast. The lowest design wind speeds were from William R Fairchild International, an airport at the base of Olympic National Park meeting the Salish Sea, and in the center of the Olympic Peninsula SWR. The design wind speeds from the more eastern airports, Whidbey Island Naval Air Station and Paine Field, are significantly higher, although still below ASCE 7-16, and those are located outside of the SWR.

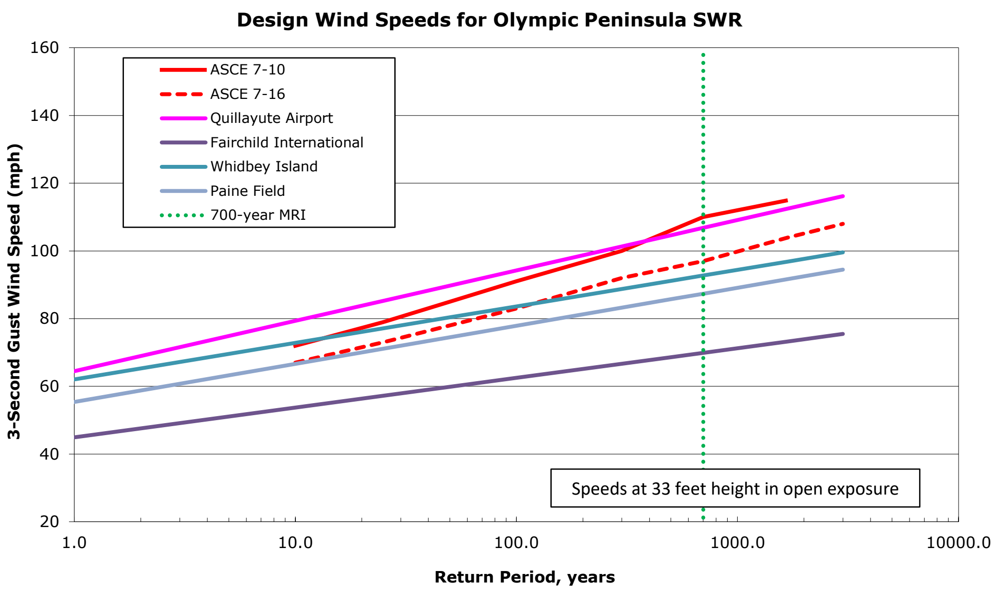

Figure 16. *Gumbel fits to non-thunderstorm wind events for all airport meteorological stations along the Olympic Peninsula.*

From our knowledge of this region and supported by the local airport data, we hypothesize that the Olympic mountains prompt channeling of the strong southerly winds often observed from the ETCs, leaving the northern edge of the Olympic Peninsula with low wind speeds as the greater wind speeds are diverted to the Washington Coast and Puget Sound. This phenomenon is so common that often, the highest wind events at Astoria Regional Airport along the Washington Coast only see winds of less than 30 or 40 mph at William F Fairchild International, as visualized by reanalysis data in Figure 17. Considering this channeling, we recommend the Olympic Peninsula SWR be modified to only encompass the western portion of Clallam County, with an approximate boundary about 35 miles inland from the Pacific Coast at a longitude of -124.00°.

Again, only the western portion of Clallam County should remain as an SWR, and this region should follow the Washington Coast design speed recommendations by Risk Category.

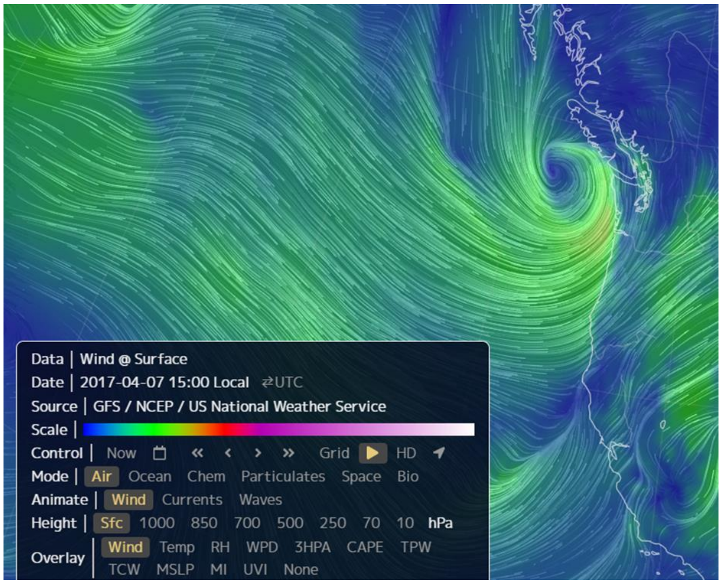

Figure 17. *Surface winds from the NCEP Reanalysis dataset demonstrating the channeled southerly winds around the Olympic Peninsula towards the Washington Coast and Puget Sound.*

LIMITATIONS

It is not certain what the basis was for the original designation in the 1982 standard of several miles on either side of the Columbia River as a SWR. It seems plausible that it was "*winds blowing … through gorges or river valleys*" as stated in ASCE 7. The airports we have examined within this SWR show no evidence of winds that are more severe than those recommended in ASCE 7-16/22 for the region. It is possible that there are specific locations where the river gorge creates significant, localized channeling for some wind directions.

The mountainous regions of the counties along the Columbia River do not contain any NCEI wind stations. Based on the terrain and our experience, it is likely that some of the mountainous regions might experience higher wind speeds, although the topographic factor (K_{zt}) in ASCE 7 is likely to capture the wind speed-up effects at hilltop locations for such topographic features.

Since the focus of this study is on the indicated SWRs, we did not attempt to estimate the wind speeds in the mountainous regions of each county. If you anticipate that there will be developments in these regions that will require more precise wind values, further data collection and analysis will be required.

Climate change is an ongoing topic of conversation in the wind engineering community as it relates to the prediction of design wind speeds. In their fifth assessment report from 2013, the Intergovernmental Panel on Climate Change (IPCC) has stated that anthropogenic climate change is projected to alter tropical cyclone intensity and frequency, which would apply to hurricanes and cyclones. Currently, the only wind loading standard which accounts for this anticipated effect is the recent release of the Australian/New Zealand Standard (AS/NZS 1170.2:2021). The climate change multiplier in this standard is only applicable to regions where the dominant extreme winds are from tropical cyclones. CPP is unaware of a reliable method to accurately quantify how climate change will affect the likelihood of future severe synoptic storms in the Pacific Northwest.

RECOMMENDATIONS FOR FURTHER WORK

Topographic simulations could be used to assess any significant channeling or wind speed-up effects more accurately in complex terrain. A terrain study would allow these effects to be identified with the use of Computational Wind Engineering (CWE). CWE simulations are useful in situations where anomalies such as terrain (hills and valleys) are known to influence wind speed and direction on a very localized basis. CWE encompasses the correct use of computational fluid dynamics (CFD) solvers for wind engineering purposes following industry standard methods. Special considerations related to atmospheric boundary layer flows and bluff body aerodynamics differentiate these CWE simulations.

Due to the lack of weather stations that would help define the transition and reductions from the strong coastal winds moving inland, we recommend an additional study using ERA5-land. The ERA5-land dataset provides 3-dimensional gridded meteorological data starting in 1973 to present that is comprised of advanced weather model output that is calibrated using global in-situ and remote sensing historical observations. It is constructed on the European Centre for Medium-Range Weather Forecasts model (ECMWF) and provides hourly meteorological variables on a 9 km grid resolution. Using this dataset to define the coastal transition more accurately would be the goal of this additional study.

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APPENDIX A: LIST OF WEATHER STATIONS FROM NCEI

Station Name	Latitude	Longitude	Elevation (m)	Excluded from results
ASTORIA	46.21	-123.77	2	✓
ASTORIA REGIONAL AIRPORT	46.16	-123.88	3	
AURORA STATE AIRPORT	45.25	-122.77	60	
BOWERMAN AIRPORT	46.97	-123.93	4	
DALLESPORT-COLUMBIA GORGE REGIONAL	45.62	-121.17	71	
DESTRUCTION IS. WA	47.68	-124.49	21	
HOOD RIVER-KEN JERNSTEDT AIRFIELD	45.67	-121.53	192	✓
KELSO-LONGVIEW AIRPORT	46.12	-122.89	6	
LA PUSH	47.92	-124.63	3	✓
NEAH BAY	48.37	-124.62	5	✓
PEARSON FIELD AIRPORT	45.62	-122.65	7	
PORT ANGELES	48.13	-123.44	5	✓
PORT ANGELES CGAS	48.14	-123.41	4	
PORT TOWNSEND	48.11	-122.76	5	✓
PORTLAND INTERNATIONAL AIRPORT	45.60	-122.61	7	
PORTLAND-HILLSBORO AIRPORT	45.55	-122.96	60	
PORTLAND-TROUTDALE AIRPORT	45.55	-122.41	8	
QUILLAYUTE AIRPORT	47.94	-124.56	56	
RACE ROCKS CAMPBELL SCIENTIFIC BC	48.30	-123.53	3	
SCAPPOOSE INDUS AIRPK ARPT	45.77	-122.86	15	
SHERINGHAM POINT BC	48.38	-123.92	22	
SMITH ISLAND WA	48.32	-122.84	15	✓
TATOOSH ISLAND WA	48.39	-124.74	31	✓
TILLAMOOK AIRPORT	45.42	-123.82	11	
WILLIAM R FAIRCHILD INT AP	48.12	-123.51	83	
SNOHOMISH CO	47.90	-122.28	185	
WHIDBEY ISLAND NAS	48.35	-122.67	14	